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RESEARCH MEMORANDUM

AERODYNAMIC HEATING OF ROCKET-POWERED RESEARCH VEHICLES AT HYPERSONIC SPEEDS

By Robert O. Piland and Katherine A. Collie

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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SUMMARY

Skin temperature measurements have been obtained on two free-flight research vehicles; measurements were made up to Mach numbers of 5.4 in one case and up to 10.4 in the other. On the first model $(M = 5.4)$, temperature measurements were obtained at nine stations (between 6.5 and 29 inches) along the 15° conical nose. The temperature distribution along the nose, at a Mach number of 5.4, indicated transition to have occurred at a Reynolds number of about 9×10^{6}. The theories of Van Driest for laminar and turbulent flow proved adequate for predicting the skin temperature histories for laminar and turbulent stations, respectively.

A skin temperature history was obtained at a single station (26.6 inches from tip) on a fineness-ratio-5 Kármán nose shape to a Mach number of 10.4. The peak skin temperature of $1,200^{\circ}$ F occurred shortly after the time of peak Mach number and calculations indicate that at this time the convective heat transfer to the model was being balanced by radiative heat transfer away from the model. The theory of Van Driest was used in calculating a skin temperature and appeared adequate up to a Mach number of about 6. Above this value, there is some divergence between calculated and measured data, possibly due to the existence of other than turbulent flow over the measuring station.

INTRODUCTION

It is well known that the problem of aerodynamic heating becomes more severe with increasing Mach number. In order to determine just what heating conditions will be encountered at higher Mach numbers, research vehicles are being flight tested, at present, to Mach numbers as high as 10.4.

The purpose of this paper is to present and discuss skin temperature measurements from two flight tests. Temperature measurements were obtained to a Mach number of 5.4 on the first flight and to a Mach number of 10.4 on the second flight.

SYMBOLS

M	Mach number
R	Reynolds number
T_o	static temperature, degrees Rankine
T	skin temperature, degrees Fahrenheit
l	length on which Reynolds number calculation is based

RESULTS AND DISCUSSION

Figure 1 presents the variation of static temperature, Mach number, altitude, and Reynolds number per foot with flight time for a three-stage vehicle which had a 15° total angle conical nose.

Figure 2 presents the variation of skin temperature with time measured at a distance of 29 inches from the nose tip. The nose cone was constructed of 0.027-inch-thick Inconel. The maximum measured temperature is seen to be 1,000° F, at which time (23.7 seconds) the vehicle is at a Mach number of 5.4.

A temperature history has been calculated using the turbulent theory of Van Driest (ref. 1) applying a conversion factor to make it applicable to the cone (ref. 2). Turbulent flow was assumed to exist from the nose tip, and the recovery factor used in calculating the adiabatic wall temperature was assumed equal to the cube root of the Prandtl number $Pr^{1/3}$ based on skin temperature (ref. 2). The ratio of specific heats γ was taken equal to 1.4. The calculated temperature history is indicated by the symbols in figure 2 and is seen to be in good agreement with the measured temperature history.

In addition to the temperatures measured at station 29, measurements were also made at eight other stations along the same 15° cone. Figure 3 presents the variation of skin temperature along the nose cone at a particular time during the flight. The flight time considered is 23.7 seconds at which time the Mach number is 5.4 and the Reynolds number per foot is 9.8×10^6. The measured temperature is indicated by the solid line and the ticks on this curve and along the center line of the cone indicate the stations at which the temperature measurements were made.

The shape of the measured curve indicates regions of laminar, transitional, and at least the early stages of turbulent flow. The abrupt change in slope of the temperature curve indicates that transition from laminar flow began at a Reynolds number of about 9×10^6. It is interesting to note that, in a flight time of only 23.7 seconds, a difference of 500° F exists between laminar-station and turbulent-station temperature measurements.

The lower broken line in figure 3 indicates temperatures calculated using the laminar theory of Van Driest (ref. 3), applying a conversion factor to make it applicable to the cone (ref. 2). The recovery factor was assumed equal to the square root of the Prandtl number (ref. 2). Fair agreement is seen to exist between the measured and calculated data at the stations where the laminar flow is believed to exist.

The upper broken line in figure 3 indicates temperatures calculated using the turbulent theory of Van Driest as described previously. Toward the aft end of the cone (station 29), where it is believed turbulent flow exists, the agreement between the measured and calculated data is quite good.

Let us now consider temperature measurements to a Mach number of 10.4 obtained during the flight test of a four-stage vehicle, which is described in reference 4.

Figure 4 presents the variation of static temperature, Mach number, altitude, and Reynolds number at the temperature measuring station, for the test vehicle. The nose shape on which the temperature measurements were made was a fineness-ratio-5 Kármán nose shape whose tip was modified to form a 15° total angle wedge. The nose skin was of 0.032-inch-thick Inconel. A sketch of the nose shape is presented in figure 5 and the temperature measuring station is shown to be 26.6 inches aft of the nose tip. The variation of skin temperature with time is also presented in figure 5 and is indicated by the solid line. A peak temperature of 1,200° F is seen to have been reached just after peak Mach number. At this time, the heating potential is still considerably higher than the skin temperature, and considering only convective heat transfer a peak temperature would not have been expected until a later flight time. The explanation for the peak at this time is that the convective heat transfer to the skin is being balanced by the radiative heat transfer away from the skin. Keeping this in mind, consider the temperature history calculated using the turbulent theory of Van Driest (ref. 1) for a cone and including radiative heat transfer. The calculated values (square symbols) agree quite well to about 28 seconds, a time which corresponds to a Mach number of about 6. At this point the measured and calculated values diverge and at the time of peak measured temperature the calculated curve is still rising rapidly. However, if transition to laminar flow is arbitrarily assumed to occur at a Reynolds number of 5×10^6 and laminar heat-transfer coefficients are used, the points indicated by the solid square symbols are obtained. The inference is that laminar flow must have actually existed on the model at this time of peak temperature. Calculations are also presented considering flat-plate theory; these are indicated by the circular symbols. At the higher temperatures, the agreement between the flat-plate calculations and the measured data is better than the calculations for the cone; this is probably fortuitous and may be due to the existence of transitional rather than turbulent flow over the measuring station for some time interval prior to time of peak temperature. The primary purpose of making the flat-plate calculations was to determine the difference in estimated maximum temperature occasioned by using the simpler flat-plate procedure. The difference is seen to be about 15 percent.

CONCLUDING REMARKS

The following observations are made from the data presented here:

1. Free-flight skin-temperature measurements have indicated transition to occur on a conical nose at a Reynolds number of about 9×10^6 at a Mach number of 5.4.

2. The theories of Van Driest for turbulent and laminar heat-transfer coefficients appear adequate for calculating skin temperature histories to Mach numbers on the order of 6.

3. Radiative heat transfer at Mach numbers of 10 can play an important role in the determination of peak skin temperature.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 26, 1955.

REFERENCES

1. Van Driest, E. R.: The Turbulent Boundary Layer for Compressible Fluids on a Flat Plate With Heat Transfer. Rep. No. AL-997, North American Aviation, Inc., Jan. 27, 1950.

2. Eckert, Ernst R. G.: Survey on Heat Transfer at High Speeds. WADC Tech. Rep. 54-70, Wright Air Dev. Center, U. S. Air Force, Apr. 1954.

3. Van Driest, E. R.: Investigation of Laminar Boundary Layer in Compressible Fluids Using the Crocco Method. NACA TN 2597, 1952.

4. Piland, Robert O.: Performance Measurements From a Rocket-Powered Exploratory Research Missile Flown to a Mach Number of 10.4. NACA RM L54L29a, 1955.

FLIGHT CONDITIONS FOR MODEL TESTED
UP TO M=5.4

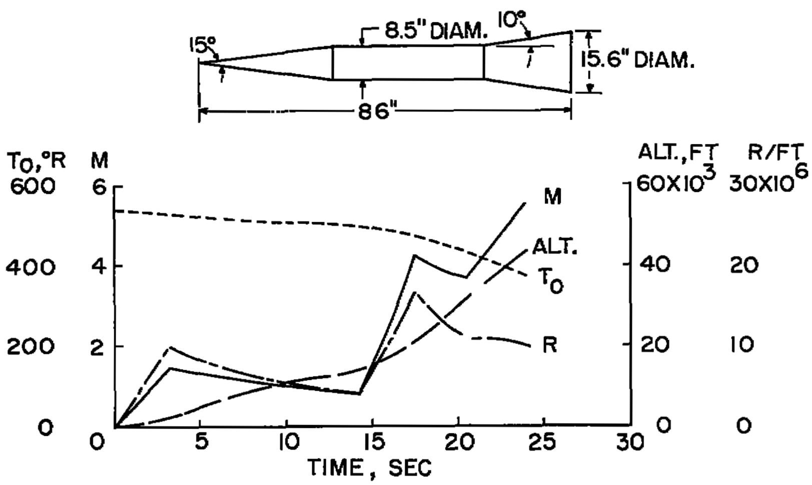

Figure 1

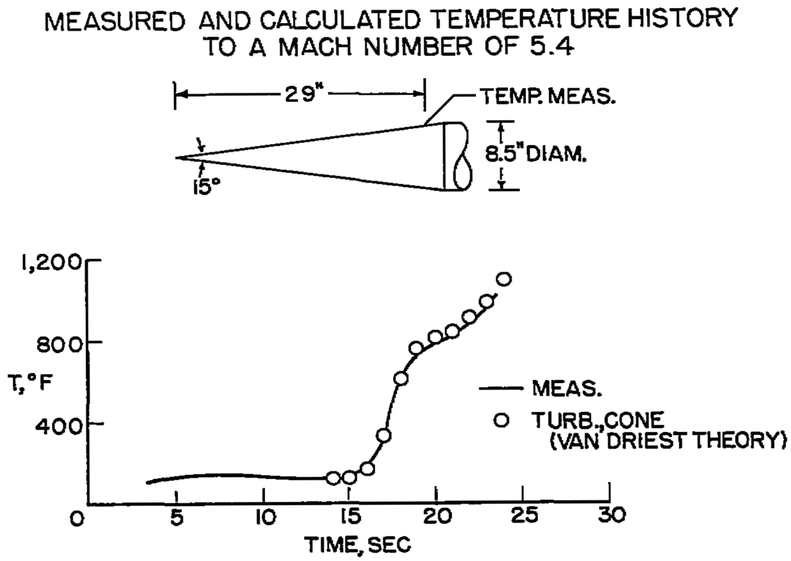

Figure 2

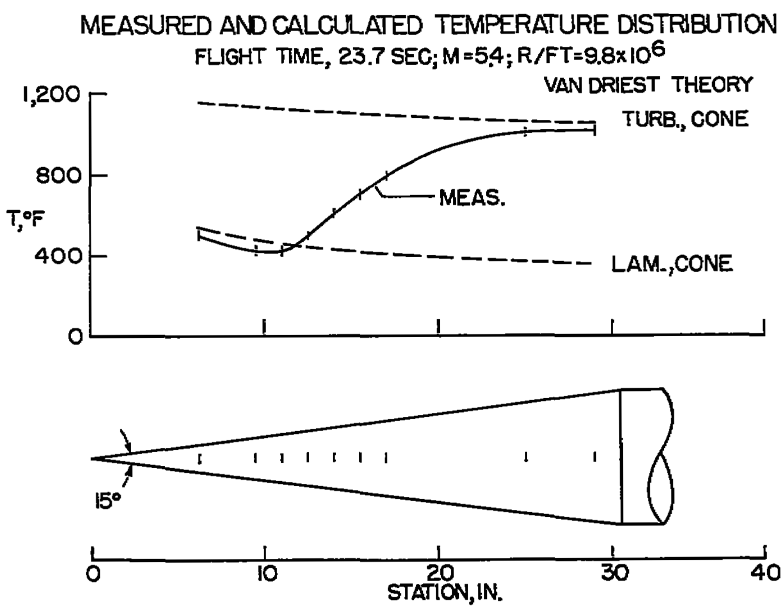

Figure 3

FLIGHT CONDITIONS FOR MODEL TESTED UP TO M=10.4

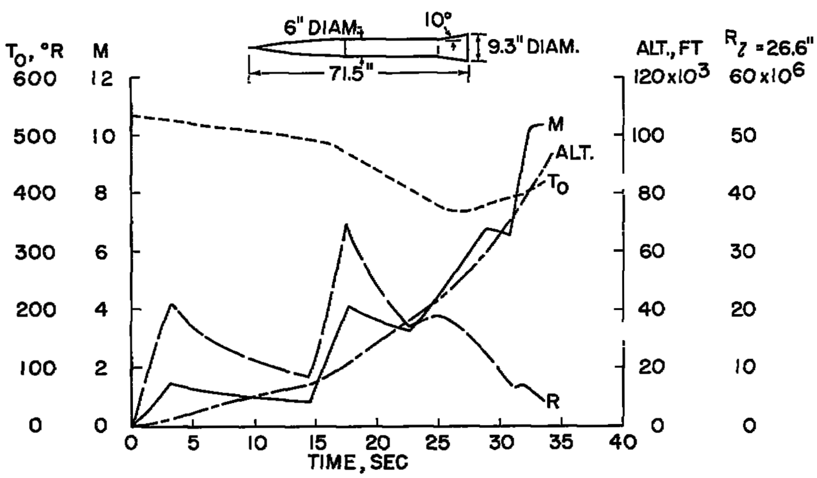

Figure 4

MEASURED AND CALCULATED TEMPERATURE HISTORY TO A MACH NUMBER OF 10.4

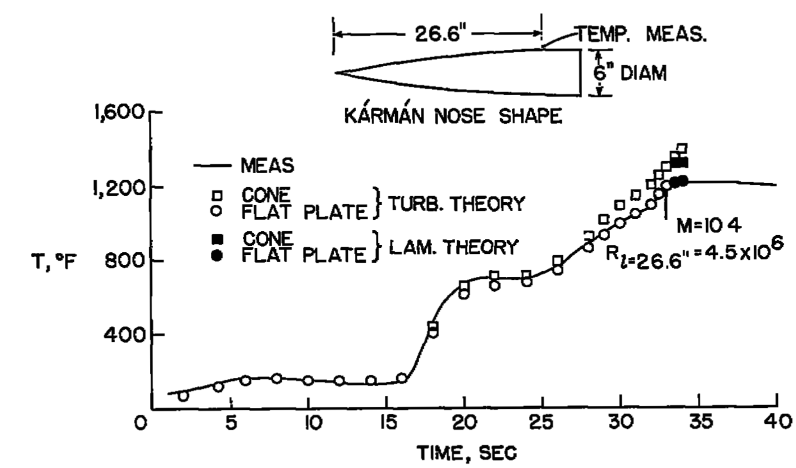

Figure 5

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